CME Arrival Time & Impact Working Team

Christine Verbeke, Leila Mays, Sandro Taktakishvilli

Team Goals

- ✳ Evaluate where we stand with **CME arrival time and impact prediction**
- ✳ Establish **community-agreed metrics** and **events** regarding CME arrival time and impact.
- ✳ Provide a **benchmark** against which future models can be assessed against
- ✳ Complementary to the CME Scoreboard (collect and display real-time CME predictions and facilitate the validation of real-time predictions).

Team Deliverables

- ✳ Catalog of **metrics** and how they relate to **user needs and science needs.**
- ✳ Model **assessments** with selected metrics for selected time intervals.
- ✳ **Online database** of model inputs, outputs, and observations.
- ✳ **Publication** describing model assessment results summarizing where we stand with CME arrival time and impact prediction.

Work with Information Architecture for Interactive Archives (IAIA) working team for online database.

Summary of team tasks

- Identify and discuss **user needs**
- Discuss and select **time intervals** to study — expand as needed
- Discuss and develop a set of **relevant skill scores**, and relate them to **user needs** and **science needs**
- Identify sources of **uncertainty**
- Produce **model/technique output** for intervals of study
- Perform model **assessments** with selected metrics

Remote collaboration

- Slack channels *(contact leads to be added)*
- Mailing list *(contact leads to be added)*
- Email
- Telecons
- Regular website updates

https://ccmc.gsfc.nasa.gov/assessment/topics/helio-cme-arrival.php

Participants – invite your colleagues

high interest

Eric Adamson* · Tanja Amerstorfer · Anastasios Anastasiadis · Nick Arge · Michael Balikhin* · David Barnes* · Francois-Xavier Bocquet · Yaireska Collado-Vega* · Pedro Corona-Romero* · Jackie Davies · Curt de Koning* · Craig DeForest* · Manolis K. Georgoulis* · Carl Henney · Bernard Jackson* · Lan Jian · Masha Kuznetsova* · Kangjin Lee · Noé Lugaz · Anthony Mannucci* · Periasamy K Manoharan* · Daniel Matthiä* · Leila Mays* · Mike McAleenan* · Slava Merkin* · Marilena Mierla · Joseph Minow* · Christian Moestl · Karin Muglach* · Teresa Nieves · Nariaki Nitta · Marlon Nunez · Dusan Odstrcil* · Mathew Owens · Evangelos Paouris · Athanasios Papaioannou · Spiros Patsourakos · vic pizzo · Pete Riley · Alexis Rouillard · Camilla Scolini · Howard Singer* · Robert Steenburgh* · Aleksandre Taktakishvili* · Manuela Temmer · W. Kent Tobiska* · Christine Verbeke* · Angelos Vourlidas · Katherine Winters* · Alexandra Wold* · KiChang Yoon · Emiliya Yordanova* · Jie Zhang ·

medium interest

Tarek Al-Ubaidi · Suzy Bingham* · Steven Brown* · Baptiste Cecconi · David Falconer · Natalia Ganushkina* · Laura Godoy* · Bernd Heber · Christina Kay · Adam Kellerman* · Burcu Kosar* · Alexander Kosovichev* · Yuki Kubo · Peter MacNeice* · Chigomezyo Ngwira* · Steve Petrinec* · Nikolai Pogorelov* · Lutz Rastaetter* · Ian Richardson* · Neel Savani* · Barbara Thompson* · Karlheinz Trattner* · Rodney Viereck · Brian Walsh · Chunming Wang* · Daniel Welling* · Yongliang Zhang* · Yihua Zheng* ·*

**attending CCMC-LWS working meeting*

Participating models

- DBM (Vrsnak & Zic)
- ElEvo (Ellipse Evolution) (Moestl)
- ElEvoHI (Ellipse Evolution based on HI) (Amerstorfer)
- Enhanced drag-based model (Hess & Zhang) [set 1 results]
- EUHFORIA (Pomoell)
- SARM (Núñez) [set 1 results]
- SUSANOO-CME
- WSA-ENLIL+Cone (Arge, Odstrcil) [set 1 results]
- *contact us to add your model*

Team Agenda

APRIL 4 • TUESDAY

9:00am – 10:15am

Metrics

- Metrics discussion and examples
- Metrics addressing user needs vs. scientific research
- Discussion questions
- 1st set of events for validation
- Preliminary model validation/results
- Alex Wold: Real-time ENLIL run validation & discussion
- Marilena Mierla (not attending): comparisons of ENLIL and EUHFORIA
- More 2-3 slide contributions from participants
- CME scoreboard discussion
- Suzy Bingham: Initial CME scoreboard verification from the UK Met Office

APRIL 5 • WEDNESDAY

10:45am – 12:00pm

Metrics & Impact of background solar wind

- Continue items remaining from Metrics session
- Scene setting presentation on quantifying the effects of background solar wind
- Discussion on impact of background solar wind, 2-3 slide contributions from participants
- Continue other discussion items from previous sessions

APRIL 6 • THURSDAY

4:45pm – 6:00pm

Summary and future plans

- Remaining discussion questions
- Quantifying progress in the field of CME arrival & impact
- Summary of team progress
- Future plans, meetings, remote collaboration

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Considerations for Event Selection

Considerations for event selection:

- ✳ Single CME events (fast and slow)
- ✳ Multiple CME events (interacting and non-interacting)
- ✳ CME events that are expected to arrive but do not (false alarm)
- ✳ Flank impact CME events
- ✳ Consider events from the ISEST WG4 wiki page
- ✳ Overlap some events with the IMF Bz and L1 working team

- ✳ For some validation methods, how many events are needed to be statistically significant?
- ✳ Event selection: Should we have a "training set", "validation set", and "test set" — where the "test" set is not revealed until a later stage?

1st set of events

small core selection to explore chosen metrics & validation techniques

- Four events: two hits, one problematic hit, and one false alarm.
- Aim for 2 hits to will **overlap** with the **IMF Bz** working team's event list to reduce the overall modeling burden (for those models that predict both arrival and Bz).
- If desired, the CME parameters provided on the website (taken from literature) can be used

A) **3 April 2010** 10:33 UT (hit)
B) **15 March 2013** 07:12 UT (hit)
C) **7 January 2014** 18:24 UT (false alarm; only a weak discontinuity arrives)
D) **15 March 2015** 01:48 UT (hit; problematic, many models predict a late arrival)

Results from 4 models for these events have been posted on our website:
https://ccmc.gsfc.nasa.gov/assessment/topics/CME/events.php#results

Validation: User Needs vs Research Needs

feedback from SWPC

- The validation of CME forecasting focused around **arrival time** because it was the easiest thing to agree on. Long term goal is to validate **intensity** and **duration** also.

- Important to realize that quantities to validate for research is **different** operations. E.g. little interest in **T** or **n** verification for operations.

- **Science research** focus is on how well model for performs for **most parameters**

- For **operations** the most important quantities are **Bz** and **v** (coupling function)

- Quantities important in this order for operations: **timing (arrival), intensity, and duration**

Validation: User Needs

feedback from SWPC

Quantities to validate:

- **timing (arrival), intensity, and duration**

- Arrival time: power grid is interested in **timing**

- Suggest using **historic ICME observations** to determine what to validate (e.g. what intensity, duration, or threshold is important to test model performance)

- **Kp** used by forecasters, but it might be useful to compare **Dst** predictions for models for their performance forecasting of storm intensity and duration.

- Always useful to provide a measure of **uncertainty**

- A **best/worst case scenario** is useful for users to make decisions

Discussion questions: models

- What are the **effects of the model inputs** on the CME arrival time and impacts
  - model parameters
  - CME parameters
  - input magnetograms
  - …

- Is there a **solar cycle dependence** on model performance?

- Do we want to **fix the CME input parameters** and input magnetograms (if applicable) for all models?

  If so, is the team comfortable for the CME parameters to be determined by an expert that is not a modeler in the CME Arrival Time Working team to remove bias?

- What are some good techniques to determine the **uncertainty/confidence** of the arrival time prediction?

Discussion

Quantities to Validate: some ideas to start

ICME...

- arrival time
- average magnetic field magnitude
- average temperature
- average speed
- duration
- resulting geomagnetic storm strengh (Kp, Dst, ...)

Skill scores/metrics

- Arrival time:
  - RMSE, mean absolute error (MAE), mean error (ME), others?
- Categorical (yes/no) predictions:
  - skill scores based on contingency tables
  - probabilistic and continuous predictions can be converted to categorical using threshold
- Probabilistic predictions:
  - Reliability diagram, Brier Skill Score, ...

Discussion questions: Quantities & Observations

what to quantities to validate, and what to compare them to

- Which **catalog** to use for ICME arrival? Take an average?
- Over what interval should **average in-situ observations** be derived? Use a catalog?
- Directly compare **time series** w/observations for some models? Time-shift model results?
- Also validate the the **magnetic cloud arrival** in addition to the shock/discontinuity?
- Validate an "**impact parameter**" extracted from model results? Compare to in-situ flux rope fit parameters?
- How can we validate and **quantify the effect of the background solar wind prediction** on the arrival time prediction?
- How do interacting or **multiple CME events**, or **SIR+CME events** impact the chosen metrics? How to quantify model performance for these events?

Discussion questions: Metrics

- What is a good baseline model or **climatology** to compare against?

- For the hit calculation:
  - **How to define a categorical yes/no** for "model predicted arrival" - human analysis of model results or algorithm? What analysis method?

  - If the model predicted arrival time is **more than x number of hours** from the observed CME arrival time is it a **hit**? Or a false alarm and miss? Vary the definition of the hit depending on user needs?

- Probabilistic prediction: what **threshold** to use for hit/miss? Vary and explore?

- How best to quantify **uncertainty** in the **skill score** results based on validation sample size, uncertainties in observations, and from any other sources.

CME Arrival Time Scoreboard

The CME scoreboard is a research-based forecasting methods validation activity which provides a central location for the community to:

- submit their forecast in real-time
- quickly view all forecasts at once in real-time
- compare forecasting methods when the event has arrived
- view the average of all forecasts for each event (ensemble).

http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard

All prediction methods are welcome and all are encouraged to participate.

Participation from the community:

- All prediction models and methods are welcome from the world-wide research
- community (currently 19 methods are registered)
- Users submit their predictions for ongoing CME events, listing their method
- assumptions and input parameters
- Researchers can then view all of the predictions, modeling details, and the
- ensemble average of all predicted arrival times submitted by participants

Community predictions for the 5 Nov 2016 CME

CME: 2016-11-05T04:48:00-CME-001

Actual Shock Arrival Time: 2016-11-09T05:28Z

Observed Geomagnetic Storm Parameters:

CME Note: Filament Eruption off the northern Hemisphere giving a very wide-angle partial halo. Another CME came off the farside and eastern limb at a similar time. Evident in SOHO and STEREO imagery after 05/0200UTC.

Predicted Shock Arrival Time	Difference (hrs)	Confidence (%)	Submitted On	Lead Time (hrs)	Predicted Geomagnetic Storm Parameter(s)	Method	Submitted By	
2016-11-08T19:00Z (-12.0h, +12.0h)	-10.47	75.0	2016-11-06T11:10Z	66.30	Max Kp Range: 4.0 - 6.0	Other (SIDC)	Leila Mays (GSFC)	Detail
2016-11-08T16:00Z (-7.0h, +7.0h)	-13.47	----	2016-11-05T17:52Z	83.60	----	WSA-ENLIL + Cone (GSFC SWRC)	Karin Muglach (GSFC)	Detail
2016-11-08T11:15Z	-18.22	57.5	---	---	Max Kp Range: 3.5 - 5.33333	Average of all Methods	Auto Generated (CCMC)	Detail
2016-11-08T10:00Z	-19.47	----	2016-11-06T00:30Z	76.97	Max Kp Range: -- - 5.0	WSA-ENLIL + Cone (NOAA/SWPC)	Barbara Thompson (GSFC)	Detail
2016-11-08T00:00Z (-9.0h, +6.0h)	-29.47	40.0	2016-11-06T01:00Z	76.47	Max Kp Range: 3.0 - 5.0	WSA-ENLIL + Cone (Met Office)	Met Office (Met Office)	Detail

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http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard

Please join! All prediction methods are welcome and all are encouraged to participate.

Community predictions for the January 7, 2014 CME (X1.2 flare):

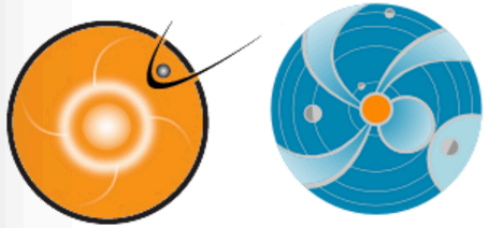
15 submissions
Average of all submissions: **12 hours early, Kp geomagnetic index 6 to 7.6**

CME: 2014-01-07T18:24:00-CME-001
Actual Shock Arrival Time: 2014-01-09T19:32Z
Observed Geomagnetic Storm Parameters:
Max Kp: 3.0

http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard

Predicted Shock Arrival Time	Difference (hrs)	Submitted On	Lead Time (hrs)	Predicted Geomagnetic Storm Parameter(s)	Method
2014-01-10T04:04Z (-16.0h, +36.0h)	8.53	2014-01-08T14:56Z	28.60	Max Kp Range: 8.0 - 8.0 Dst min. in nT: -300	COMESEP
2014-01-09T19:26Z (-10.0h, +10.0h)	-0.10	2014-01-07T21:00Z	46.53	----	STOA
2014-01-09T13:00Z (-7.0h, +7.0h)	-6.53	2014-01-08T23:17Z	20.25	Max Kp Range: 6.0 - 8.0	WSA-ENLIL + Cone
2014-01-09T12:00Z (-7.0h, +7.0h)	-7.53	2014-01-08T06:32Z	37.00	----	WSA-ENLIL + Cone
2014-01-09T11:22Z (-11.7h, +9.1h)	-8.17	2014-01-09T18:57Z	0.58	Max Kp Range: 3.0 - 5.0	Ensemble WSA-ENLIL + Cone (GSFC SWRC)
2014-01-09T08:02Z	-11.50	2014-01-08T16:37Z	26.92	----	Expansion Speed Prediction Model
2014-01-09T08:00Z	-11.53	2014-01-08T01:31Z	42.02	Max Kp Range: 6.0 - 7.0	WSA-ENLIL + Cone (NOAA/SWPC)
2014-01-09T06:35Z	-12.95	---	---	Max Kp Range: 6.0 - 7.625	Average of all Methods
2014-01-09T04:30Z (-2.5h, +2.5h)	-15.03	2014-01-08T05:02Z	38.50	Max Kp Range: 5.0 - 8.0	Other (SIDC)
2014-01-09T04:00Z (-6.0h, +6.0h)	-15.53	2014-01-08T09:42Z	33.83	----	DBM
2014-01-09T02:00Z	-17.53	2014-01-08T17:53Z	25.65	Max Kp Range: 8.0 - 9.0	BHV
2014-01-09T01:00Z	-18.53	2014-01-08T23:00Z	20.53	Dst min. in nT: -142 Dst min. time: 2014-01-09T12:00Z	Anemomilos
2014-01-09T00:38Z (-7.0h, +7.0h)	-18.90	2014-01-08T00:41Z	42.85	Max Kp Range: 6.0 - 8.0	WSA-ENLIL + Cone (GSFC SWRC)
2014-01-09T00:17Z (-6.9h, +9.2h)	-19.25	2014-01-08T04:11Z	39.35	Max Kp Range: 6.0 - 8.0	Ensemble WSA-ENLIL + Cone (GSFC SWRC)
2014-01-08T22:00Z	-21.53	2014-01-08T03:17Z	40.25	Dst min. in nT: -146 Dst min. time: 2014-01-09T11:00Z	Anemomilos
2014-01-08T12:30Z	-31.03	2014-01-08T05:58Z	37.57	----	ESA

Please join! All prediction methods are welcome and all are encouraged to participate. There are currently 19 registered models.



CME ScoreBoard

Login

CME Scoreboard

CME arrival time predictions from the research community:
The CME Scoreboard (developed at the Community Coordinated Modeling Center, CCMC) is a research-based forecasting methods validation activity which provides a central location for the community to:

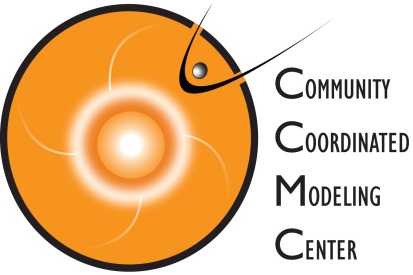
- submit their forecast in real-time
- quickly view all forecasts at once in real-time
- compare forecasting methods when the event has arrived

Using this system:

- Anyone can view prediction tables
- Users can enter in your CME shock arrival time forecast after logging in:
  - Registered Users: Begin by finding your CME under the "Active CMEs" section, then click "Add Prediction" and select your forecasting "Method Type" from the list. (Click here to register for an account.)
  - Power Users: If you do not see your CME listed under the "Active CMEs" section, click "Add CME" to get started (Click here to request power user privileges). To enter the actual CME shock arrival time, click "*Edit CME*" after you are done entering your prediction(s).
- Click here to see a list of registered methods. If you would like to register your prediction method, please send an email to M. Leila Mays or Yihua Zheng with your model/technique details.
- Click here for more detailed instructions.

http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard

Anyone can view predictions, please register to submit predictions.



Begin by clicking **Add Prediction** under the "Active CMEs" section and select your forecasting "Method Type" from the list.
While logged in, if you do not see any CMEs listed under the "Active CMEs" section, click **Add CME** to get started.

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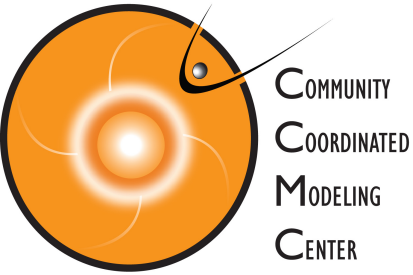
Active CMEs:

Note: If you can't find your CME below, please click "Add CME" to add your CME. To enter the actual CME shock arrival time, click "*Edit CME*" after you are done entering your prediction(s).

CME: 2015-01-01T00:00:00-CME-001
Edit CME
Delete CME
Add Prediction
No Prediction Entered for this CME yet!

http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard



http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard

Prediction Form for CME (2014-01-01T00:00:00-CME-001)

Enter submission time in format (yyyy-MM-dd'T'HH:mm'Z' i.e. 2012-07-12T16:52Z) :

Method Type (details):

Prediction notes: (Please include all initial conditions/parameters used in your prediction)

- --- Select ---
- Anemomilos
- Ballistic projection
- BHV
- DBM
- ECA
- ESA
- H3DMHD (HAFv.3+3DMHD)
- HAFv.3
- HAFv2w
- HI J-map
- Other
- Other (ips.gov.au)
- Other (SIDC)
- STOA
- TH
- WSA-Enlil + Cone
- WSA-Enlil + Cone (GSFC SWRC)
- WSA-Enlil + Cone (NOAA/SWPC)

Enter predicted CME shock arrival time in format (yyyy-MM-dd'T'HH:mm'Z' i.e. 2012-07-12T16:52Z) :

Positive Error Bar in hours (optional):

Negative Error Bar in hours (optional):

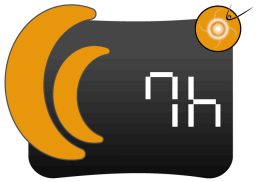
Kp Range Lower Limit (optional):

Kp Range Upper Limit (optional):

Dst min. in nT (optional):

Dst min. time in format (yyyy-MM-dd'T'HH:mm'Z' i.e. 2012-07-12T16:52Z) (optional):

CME Arrival Time Scoreboard



Suggested improvements coming soon:

- Automatic forecast submission via an XML file
- Mailing list that notifies users when a new CME has been added to the scoreboard
- Separate geomagnetic storm scoreboard that can link to CME scoreboard

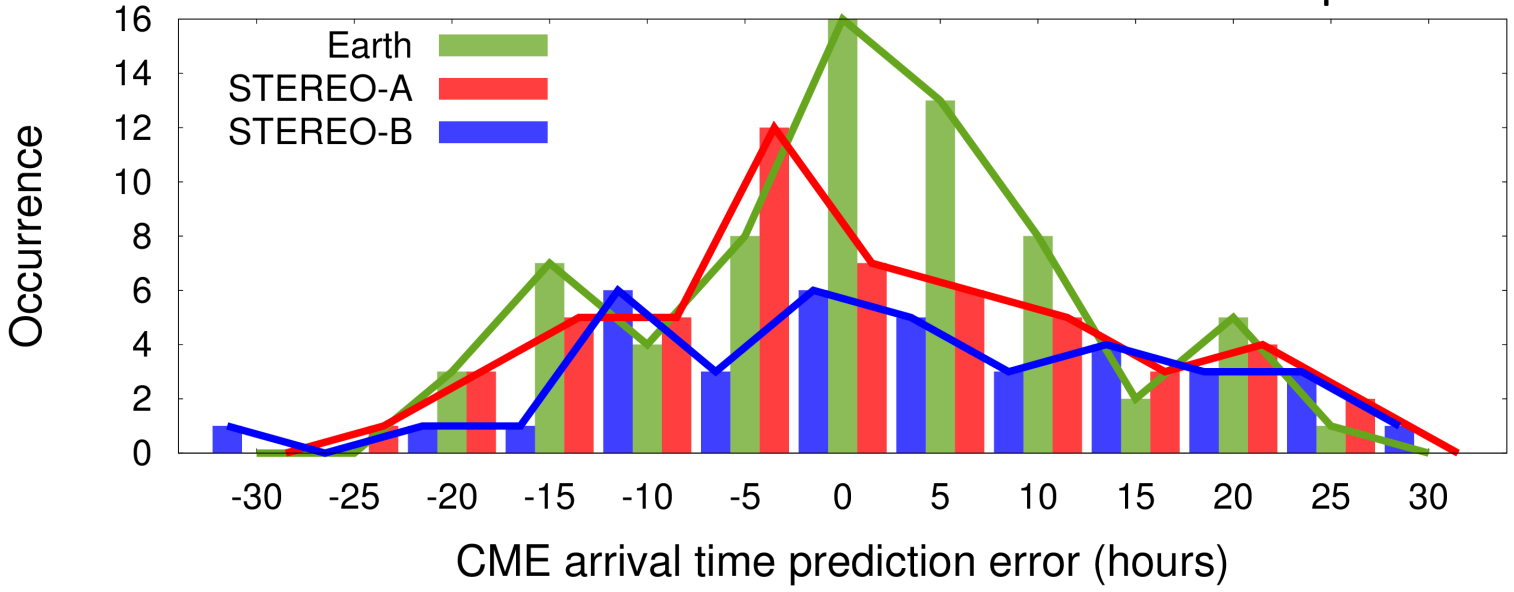
Future plans:

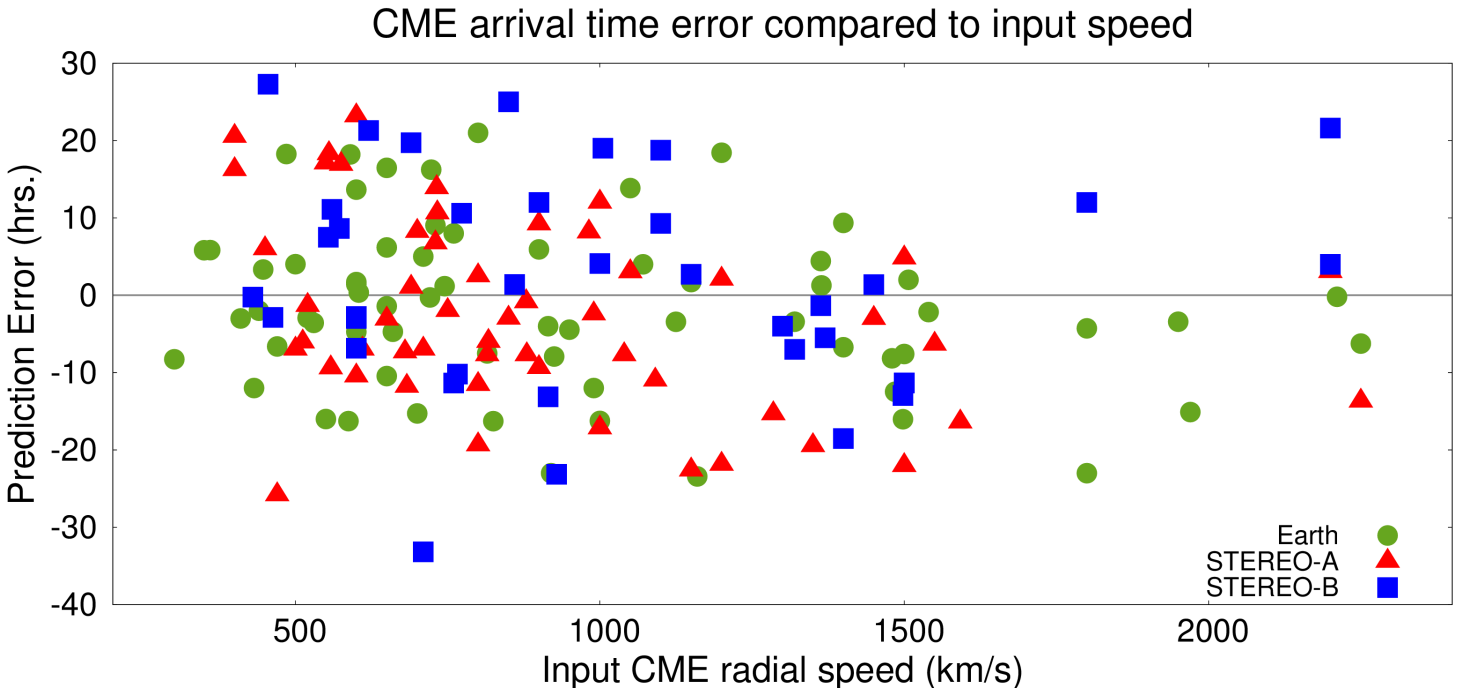
- Showing data in table in plot form
- Automatic skill score calculations
- Quality factor for confidence in observed ICME associated shock arrival
- Quality factor for confidence in linking observed ICME arrival with CME in coronagraph
- Your ideas?

http://kauai.ccmc.gsfc.nasa.gov/CMEscoreboard

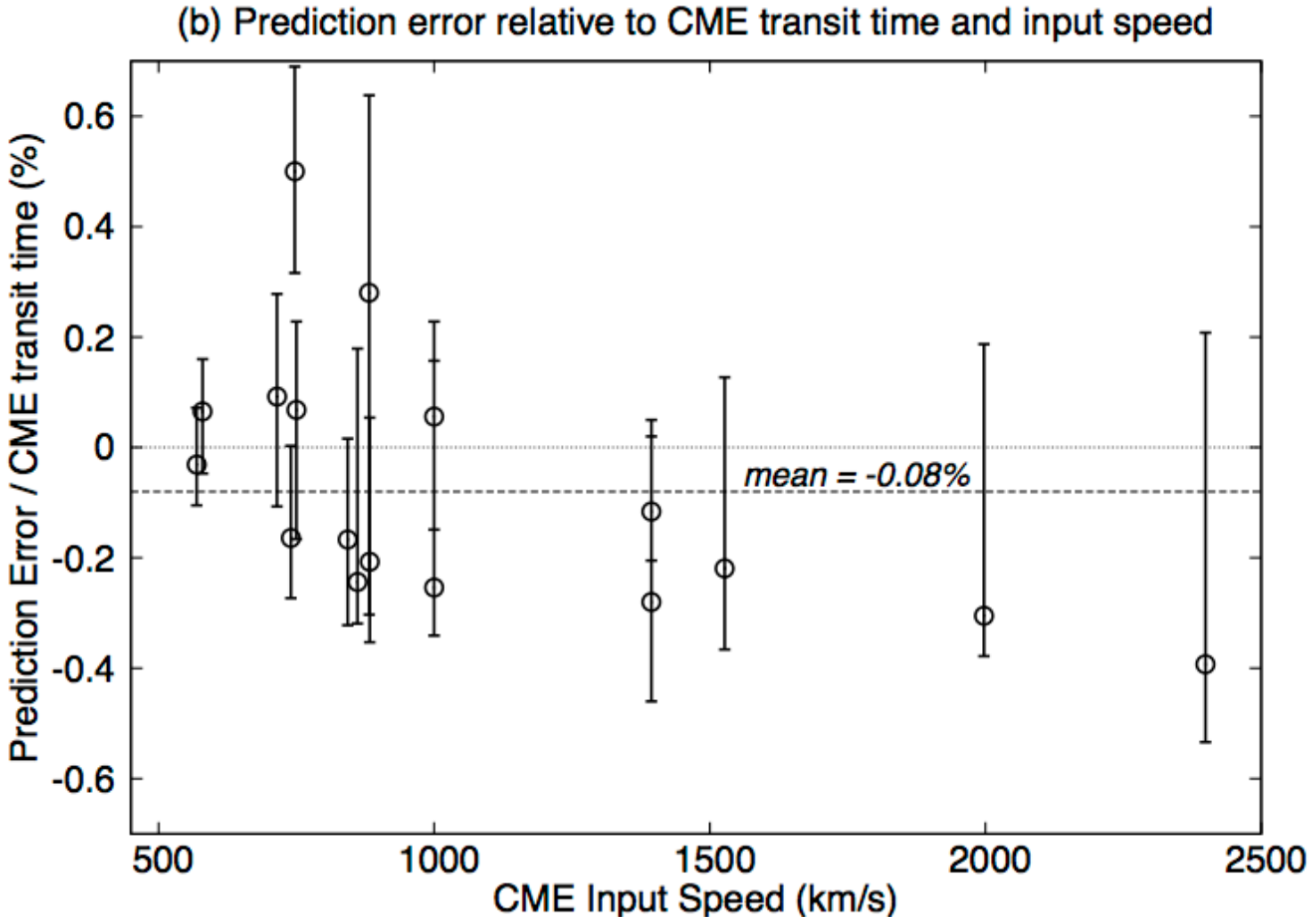
Discussion:
CME arrival time & impact validation techniques

CME Arrival Time Error Validation Examples

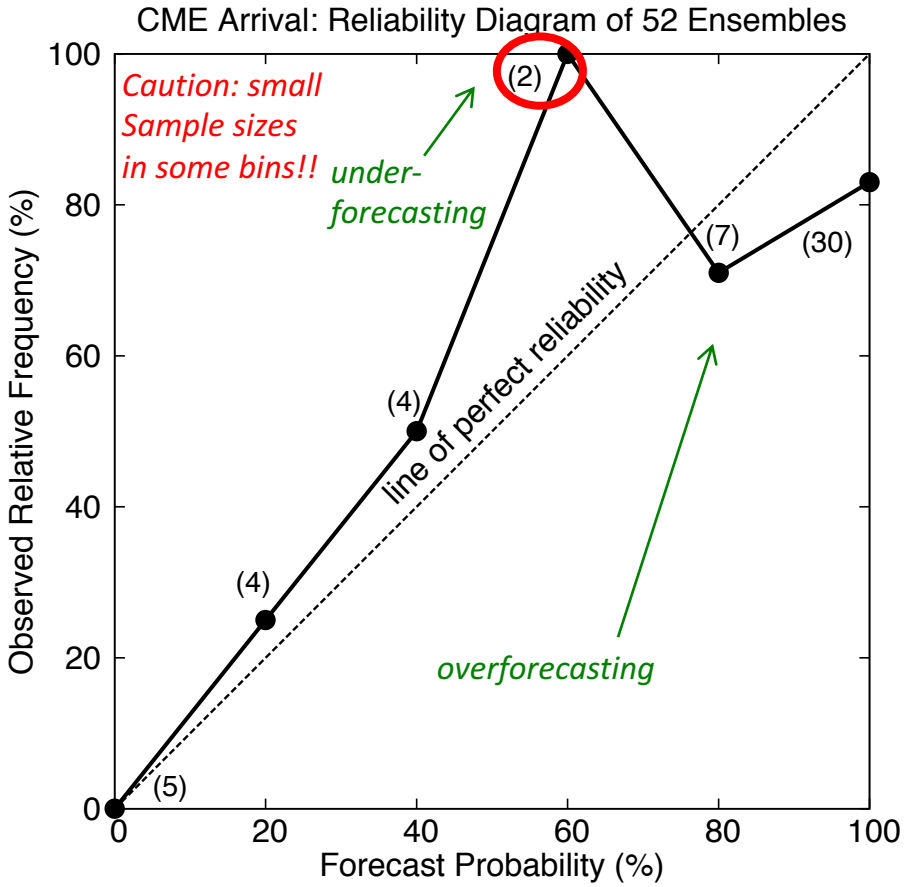




CME Arrival Time Error Validation Examples



Assessment: Confidence (likelihood) in CME arrival



- Example reliability diagram for CCMC/SWRC arrival time forecasts
- Underforecasting in the forecast bins between 40-80%
- Slightly overforecasting in the 80-100% forecast bins

Need to improve confidence in CME arrival forecast:

- Consider better way of translating CME "impact parameter" into probability that the CME will arrive which more accurately represents head-on vs. grazing impacts (and the ranges in between)

Likelihood of CME arrival forecast verification: Brier Score

Using the forecast probability about the likelihood that the CME will arrive submitted on the scoreboard.

A method defining the mean squared probability forecast errors is the Brier Score:

$$BS = \frac{1}{N}\sum_{i=1}^{N}(p_i - o_i)^2$$

N = number of events,
p_i = forecast probability of occurrence for event i,
o_i = 1 if the event was observed to occur and 0 if it did not.

Ranges from 0 to 1, with 0 being a perfect forecast.

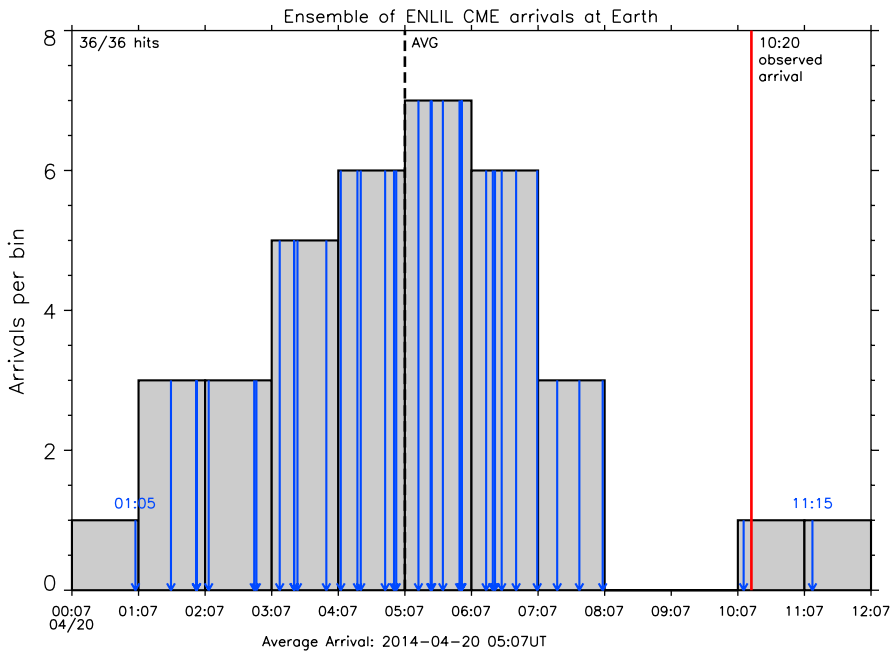
The Brier Skill Score (BSS) is the the Brier score relative to climatology

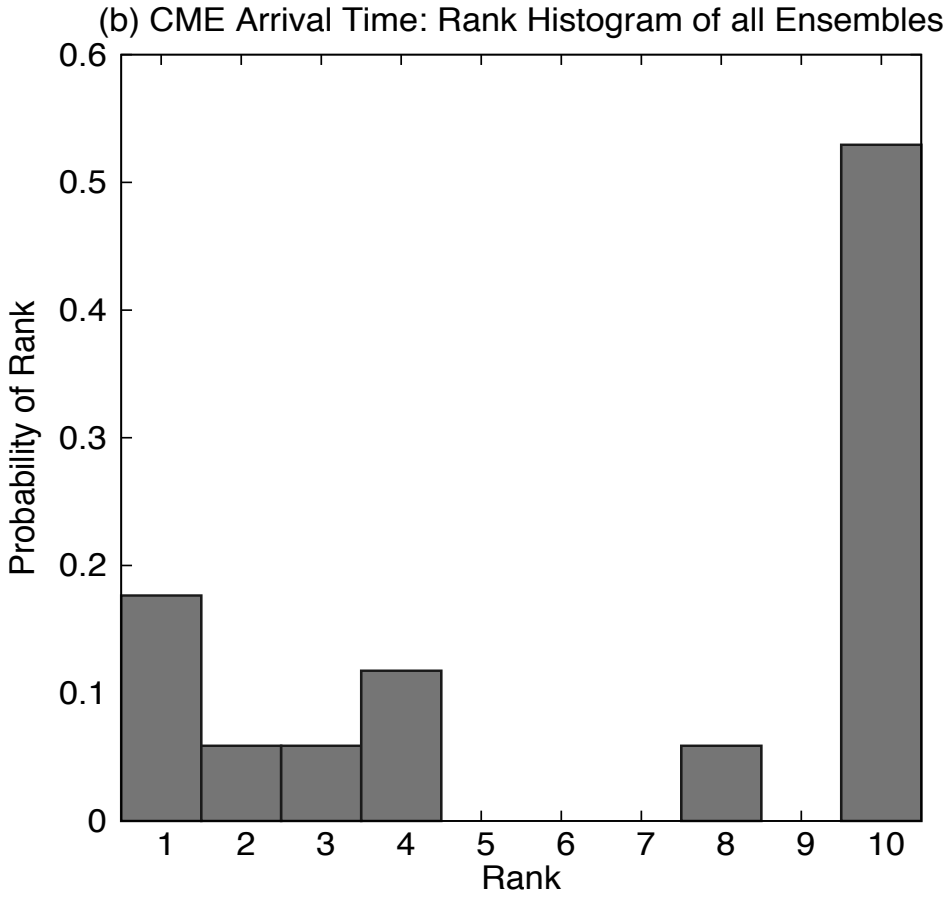
Note: confidence intervals should be computed for verification scores

Likelihood of CME arrival forecast verification: Reliability

How well does the ensemble spread represent the true variability of the observations?

The U-shaped rank histogram for suggests undervariability, indicating that these ensembles to not sample a wide enough spread in CME input parameters.





Ensemble Validation Summary

• Ensemble modeling gives a probabilistic forecast which includes an estimation of arrival time uncertainty from the spread in predictions and a forecast confidence in the likelihood of CME arrival.

• First results for 30 event sample: mean absolute arrival time error of 12.3 hours, RMSE of 13.9 hours, and mean error of -5.8 hours (early bias), comparable with other CME arrival time prediction errors reported in the literature.

• It was found that the correct rejection rate is 62%, and the false-alarm rate is 38%.

• Brier Score of 0.15 shows that the likelihood of CME arrival prediction is fairly accurate.

• However, the reliability diagram shows that the ensemble simulations are underforecasting the likelihood that the CME will arrive in the forecast bins between 20-80%, and slightly overforecasting in the 1-20% and 80-100% forecast bins.

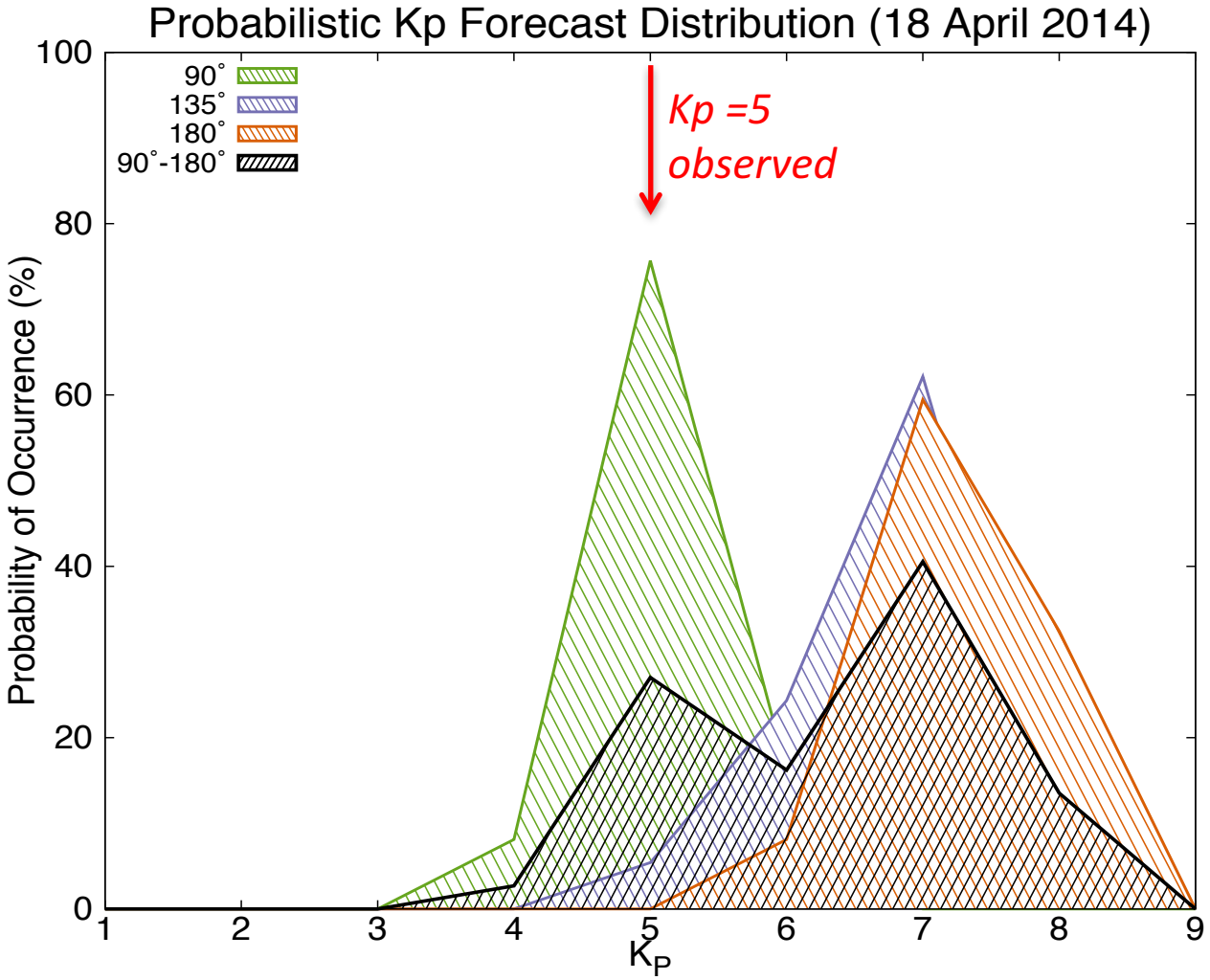
• For 8 out of 17 of the ensemble runs containing hits, the observed CME arrival was within the spread of ensemble arrival time predictions. The initial distribution of CME input parameters was shown to be an important influence on the accuracy of CME arrival time predictions. The rank histogram suggests undervariability in initial conditions; i.e., these ensembles do not sample a wide enough spread in CME input parameters.

• The observed Kp was within ±1 of the predicted mean Kp for 11 out of 17 of the ensembles.

• Kp prediction errors: mean absolute error of 1.4, RMSE of 1.8, and mean error +0.4.

• Overall tendency for the overprediction of Kp, for CME input speeds above ~1000 km/s.

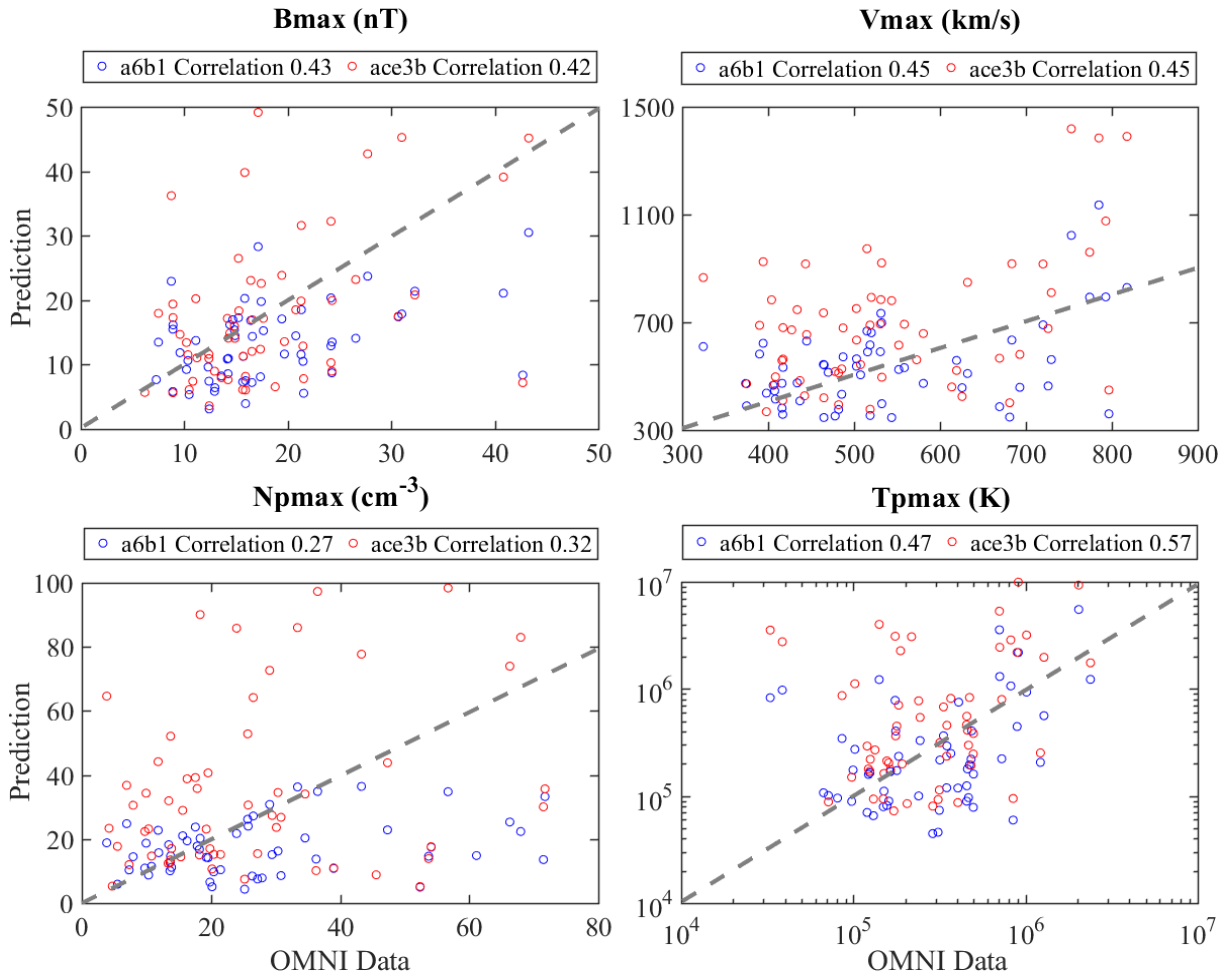
18 April 2014 CME: Distribution of Kp probability forecast



Kp is forecast using ENLIL predicted solar wind quantities at Earth as input to the Newell et al. (2007) coupling function for three clock angle scenarios (Θ_C=90°, 135°, and 180°) and all three angles combined, assuming equal likelihood.

- Observed Kp: 5 during period 12:00-15:00 UT on 20 April.
- 84% of the forecasts fall between Kp = 5 to 7. The most likely forecast is for Kp=7 at 41%, followed by Kp=5 at 27% and Kp=6 at 16% likelihood of occurrence.
- Using the mean Kp forecast of Kp=6, the prediction error is $Kp_{error} = Kp_{predicted} - Kp_{observed} = 1$ (overprediction)

Simulated vs. Observed CME Parameters



- The difference from **different observation data** can affect the results. For example, the difference of V_{max} from OMNI and ACE is >200 km/s for 3 CMEs. The correlation for N_{pmax} is weaker if using ACE
- In several cases where the CME V_{max} is overestimated, there are interactions of multiple CMEs

- Using the fixed parameters (a6b1), the V_{max} and N_{pmax} are underestimated. They are overestimated in the case of self-adjusted parameters (ace3b)
- Similar trends are found for the correlations of mean values of CME parameters. The mean temperature are overestimated in both settings

From Lan Jian